



Optimizing Seeding Rates for Organic No-Till and Tillage-Based Black Bean Production



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Background

Organic dry bean (*Phaseolus vulgaris*) production faces challenges related to weed management, yield stability, and profitability, particularly when reducing tillage. Due to limited research on organic dry bean production, farmers often base their seeding rates on conventional practices. However, differences in agronomics and market prices in organic production may lead to optimal seeding rates that diverge from conventional recommendations. While black bean shows potential when no-till planted into rolled-crimped cereal rye (*Secale cereale*), inconsistent weed suppression and lower yields relative to tillage-based production remain a concern. Increasing seeding rates relative to tillage-based organic production has been shown to improve weed suppression and yield in organic no-till soybean systems, but impacts in dry bean production are less understood. Trials were conducted in both tillage-based and no-till systems to evaluate the impact of increased organic black bean seeding rates on weed suppression, yield, and profitability and assess whether different rates are needed when deploying organic no-till methods in dry bean. The study took place during the 2022 and 2023 growing seasons at Aurora, NY, and Alburgh, VT.

Materials and Methods

Field experiments were conducted in 2021-2022 and 2022-2023 at two locations: Borderview Research Farm in Alburgh, VT, and Musgrave Research Farm in Aurora, NY. Both locations for the tillage-based and no-till study used a randomized complete block design (RCBD) with four replicates. Each experimental unit consisted of a single black bean seeding rate, with a minimum plot size of 10 by 20 feet, containing four rows spaced 30 inches apart. Additional trial management details are provided in Table 1.

Table 1. Management details for trials at Aurora, NY & Alburgh, VT in 2021-2022 & 2022-2023.

| Location | Borderview Research Farm, Alburgh, VT | | Musgrave Research Farm, Aurora, NY | |
|--|--|--|--|--|
| | 2021-2022 | 2022-2023 | 2021-2022 | 2022-2023 |
| Trial Years | 2021-2022 | 2022-2023 | 2021-2022 | 2022-2023 |
| Soil type | Benson rocky silt loam, over shaly limestone, 8 to 15 % slopes | | Lima silt loam, 3-8% slopes | |
| Previous crop | Spring wheat | Spring wheat | Sorghum sudangrass/buck wheat (fall cover crop) | Cereal rye (mulched fallow) |
| Tillage operations in tilled trials | Pottinger TerraDisc (3x) | Pottinger TerraDisc (3x) | Moldboard plow, disc, rolling harrow, cultimulcher | Chisel Plow |
| Plot size | 10ft × 20ft | 10ft × 20ft | 10ft × 45ft | 10ft × 45ft |
| Cover crop information in no-till trials | Cereal rye (var. ND Gardner) planted 20-Sep 2021 at 160 lbs/ac | Cereal rye (var. ND Gardner) planted 17-Sep 2022 at 160 lbs/ac | Cereal rye (var. ND Gardner) planted 11-Sep 2021 at 160 lbs/ac | Cereal rye (var. ND Gardner) planted 21-Sep 2022 at 160 lbs/ac |

| | | | | |
|--|---|---|--|--|
| Weed management in tilled trials | Inter-row cultivation x1 with Schmotzer Hoe with S-tine shanks and hand-weeding in mid-July | Inter-row cultivation x1 with Schmotzer Hoe with S-tine shanks and hand-weeding in mid-July | Inter-row cultivation 2x with John Deere S-tine cultivator | Inter-row cultivation 3x with John Deere S-tine cultivator |
| Black bean planting date in no-till trials | 6-June 2022 | 1-June 2023 | 25-May 2022 | 21-June 2023 |
| Black bean planting date in tilled trials | 31-May 2022 | 31-May 2023 | 25-May 2022 | 21-June 2023 |
| Black bean harvest date in no-till trials | 29-Sept 2022 | 4-Oct 2023 | 11-Oct 2022 | 20-Oct 2023 |
| Black bean harvest date in tilled trials | 22-Sept 2022 | 3-Oct 2023 | 25-Oct 2022 | 10-Oct 2023 |

Although the same five seeding rates were targeted, actual seeding rates differed slightly between sites in 2022 (Table 2). In Aurora 2022, the five seeding rates were 75,000; 150,000; 225,000; 300,000; and 375,000 seeds/ac. The five seeding rates in Alburgh 2022 were 60,000; 120,000; 180,000; 240,000; and 300,000 seeds/ac. In 2023, both sites were planted using the same rates as Alburgh in 2022. In the lowest seeding rate plots, 0 seeds/ac subplots were established by removing all plants in a randomized 5 by 5-foot sub-area to evaluate weed growth in the absence of black bean competition.

Table 2. List of black bean seeding rates at Alburgh, VT & Aurora, NY in 2022 & 2023.

| Treatment | Black bean seeding rate: VT 2022 & 2023; NY 2023 | Black bean seeding rate: NY 2022 |
|------------------|---|--|
| A | 60,000 seeds/ac (with 0 seeds/ac sub-plot) | 75,000 seeds/ac (with 0 seeds/ac sub-plot) |
| B | 120,000 seeds/ac | 150,000 seeds/ac |
| C | 180,000 seeds/ac | 225,000 seeds/ac |
| D | 240,000 seeds/ac | 300,000 seeds/ac |
| E | 300,000 seeds/ac | 375,000 seeds/ac |

Cereal rye ('ND Gardner') was no-till drill seeded at 160 lbs/ac at a target depth of 1 inch with 7.5-inch row spacing. Cereal rye termination with a roller-crimper occurred between 50% to 100% anthesis or the soft dough growth stage. For the tilled trials, a cone seeder was used in Alburgh, while a no-till planter was used in Aurora. Tilled trials did not have a cover crop prior to black bean planting, except in Aurora 2023, where cereal rye was drill-seeded in fall 2022. The cereal rye was terminated with a chisel plow in mid-April 2023, and no further seedbed preparation was performed.

Organic black beans (cv. 'Zorro') were no-till planted in 30-inch rows at a target depth of 1.5 to 2.5 inches at the five treatment rates. Black bean seeds were sourced from Seneca Grain & Bean (Penn Yan, NY) and inoculated with OMRI-listed Exceed Garden Combination. At the time of planting, 500 lbs/ac of pelletized poultry manure (5-4-3 analysis) was applied. Graphite or talc was used to ensure proper seed flow and singulation. Seed-to-soil contact and planting depth were optimized using a seed firming wheel, closing wheels, and additional weight or hydraulic down pressure.

Prior to roller-crimping, cereal rye biomass was sampled from a randomly placed 0.5 m² quadrat per block, oven-dried at 140°F for one week, and weighed. Weed biomass was collected approximately 11 weeks after black bean planting at the late reproductive stages (R6-R7). Biomass samples were clipped from a 0.5 m² quadrat per plot, including the 0 seeds/ac subplots. Quadrats were centered over the bean row and randomly placed within the middle two rows to minimize edge effects. In 2022, Alburgh used two 0.25 m² quadrats per plot to account for high spatial variability in weed biomass. Weed biomass samples were dried and weighed as described for the cover crop samples. Black bean yield sampling occurred at physiological maturity (R9 growth stage). Two 1-meter sections within the middle two rows of each plot were harvested by clipping plants at the soil surface. The total number of plants along the sampled row sections was recorded to determine black bean density. Black bean plants were air-dried in a well-ventilated, unheated space before mechanical threshing. Yield samples were dried following the same protocol as biomass samples. All yield data were adjusted to 14% moisture.

Weather Data

Table 3. Weather data for Alburgh, VT and Aurora, NY in 2022 and 2023.

| Site | | May | June | July | Aug. | Sept. | Oct. | Avg./Total | |
|----------------|---------------|---------|------|------|------|-------|------|------------|------|
| Alburgh | | | | | | | | | |
| Temperature | 2022 | 59.0 | 64.4 | 69.8 | 69.3 | 59.4 | 49.6 | 61.9 | |
| | 2023 | 55.8 | 64.8 | 71.1 | 66 | 63.1 | 53.2 | 62.2 | |
| | 30-Avg. | 56.7 | 65.7 | 70.2 | 68.4 | 60.8 | 48.4 | 62.1 | |
| | Precipitation | 2022 | 4.2 | 7.0 | 2.3 | 7.0 | 5.1 | 2.6 | 28.1 |
| | | 2023 | 1.6 | 3.5 | 9.9 | 5.8 | 2.5 | 6.4 | 29.7 |
| | | 30-Avg. | 3.5 | 4.1 | 3.9 | 4.3 | 3.5 | 4.6 | 22.2 |
| Aurora | | | | | | | | | |
| Temperature | 2022 | 61.0 | 66.4 | 72.0 | 71.1 | 62.2 | 53.1 | 64.2 | |
| | 2023 | 54.7 | 65.5 | 72.3 | 66.6 | 62.4 | 54.7 | 62.8 | |
| | 30-Avg. | 57.7 | 66.7 | 71.1 | 69.4 | 63.0 | 51.8 | 63.1 | |
| | Precipitation | 2022 | 3.1 | 3.3 | 2.0 | 5.0 | 5.4 | 0.8 | 19.6 |
| | | 2023 | 2.6 | 7.0 | 3.9 | 4.2 | 2.4 | 3.2 | 23.2 |
| | | 30-Avg. | 3.3 | 3.9 | 3.6 | 3.5 | 3.9 | 3.9 | 21.2 |

Based on weather data from NOAA Regional Climate Center. Temperature is in units of Fahrenheit (°F), and precipitation is in units of inches. Historical averages are for 30 years of NOAA data 1993-2023 from Saint-Bernard-de-Lacolle, Québec, Canada, and Aurora Research Farm, New York, USA.

Weather data and 30-year averages were retrieved from the NOAA Regional Climate Center's CLIMOD 2 (Table 3). Data for Alburgh, VT was retrieved by the nearest weather station in Saint-Bernard-de-Lacolle, Québec, Canada. Data for Aurora, NY was retrieved by the on-farm from Aurora Research Farm, New York, USA. Average growing season temperatures in Alburgh 2022 and 2023 were similar to the 30-year average. Total growing season precipitation in Alburgh for both trial years was greater than the 30-year average. In Aurora, relative to the 30-year average, 2022 was a hotter and drier growing season, while 2023 was a cooler and wetter growing season.

Statistical Analysis

All data were analyzed using R version 4.4.1 (R Core Team, 2024). In testing the relationship between black bean seeding rate and density, a linear mixed effect model (Pinheiro et al., 2016) was used with the intercept set at 0.

A non-linear framework was used to assess major mixed-effects models in the experiment. All models utilized a random effect structure of Block nested in Year, including the linear mixed-effect model. A rectangular hyperbolic model (Spitters, 1983) was used to evaluate the relationship between weed biomass and black bean density, and can be described as:

$$B_w = \frac{Y_0}{1 + i_w D_b}$$

where B_w is weed biomass (lbs/ac); Y_0 is the estimated weed biomass (lbs/ac) in the absence of black bean plants (0 seed/ac subplot); i_w is the reduction in weed biomass per black bean plant (ac/plant) which reflects the initial slope of the relationship. The i_w parameter defines the hyperbolic shape, with higher values indicating a steeper initial slope, and D_b is black bean density (plants/ac) at harvest.

An asymptotic model (Pinheiro and Bates, 2000) was used to describe the relationship between black bean seeding rate and yield. The model was modified to pass through the origin since there would be no black bean yield at a seeding rate of 0 seed/ac. The model was established as:

$$Y_B = a \left(1 - e^{(-e^b R_B)} \right)$$

where Y_B is black bean yield (lbs/ac); a represents the maximum possible yield; b denotes the natural logarithm of the rate constant; R_B is black bean seeding rate (seeds/ac).

A partial budget analysis was conducted to identify the most profitable black bean seeding rate. For each experimental plot, partial return was calculated as:

$$P_r = (Y_B \times M_p) - (B_r \times C_s)$$

where P_r is partial return (\$/ac); Y_B is black bean yield (lbs/ac); M_p is the estimated mean market price of \$0.63/lb for organic food-grade black bean in 2023 (USDA-AMS, personal communication, 2023); B_r is black bean seeding rate (seeds/ac); and C_s is black bean seed cost of \$0.00048/seed (\$48 for a bag of ~100,000 seeds). Because a “partial” budget analysis was conducted, only seed costs were considered in evaluating potential expenses.

To determine the economic optimum seeding rate, partial returns across seeding rates were modeled using a quadratic function (Liebert and Ryan, 2017; Menalled et al., 2021):

$$P_r = (a \times B_r^2) - (b \times B_r)$$

where P_r is partial return (\$/ac), B_r is black bean seeding rate (seeds/ac); a and b are constants. The quadratic model was used to identify the seeding rate that maximizes partial return, representing the economic optimum for the system.

Results

Effect of black bean seeding rate on black bean density

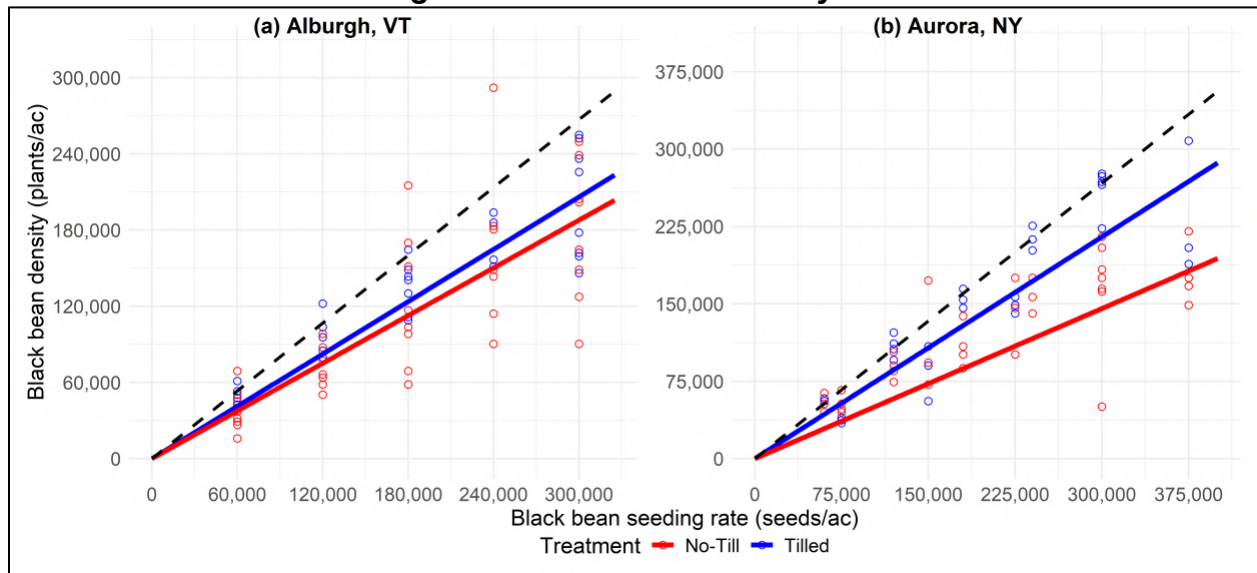


Figure 1. Effect of black bean seeding rate (seeds/ac) on black bean density (plants/ac) in no-till and tilled system in (a) Alburgh, VT and (b) Aurora, NY pooled over 2022 and 2023. The red lines and data points represent the no-till trials and the tilled trials are denoted in blue as indicated by the legend. The dashed black lines indicate expected germination at 89% based on seed tag information for black bean (cv. “Zorro”).

Across both sites, tilled systems outperformed no-till in terms of black bean density establishment. As seeding rates increased across both sites and tillage systems, black bean density also increased (Figure 1; $P < 0.001$). However, the observed densities increasingly deviated from the target density at higher seeding rates. No-till exhibited a greater deviation from the target density compared to tilled systems. In Aurora, the

difference in density between the two management systems was more pronounced than in Alburgh. On average, black bean density in Alburgh's no-till system was 114,000 plants/ac, compared to 129,000 plants/ac in the tilled system. A similar trend was observed in Aurora, where no-till plots averaged 121,000 plants/ac, compared to 145,000 plants/ac in tilled plots.

Effect of black bean density on weed biomass

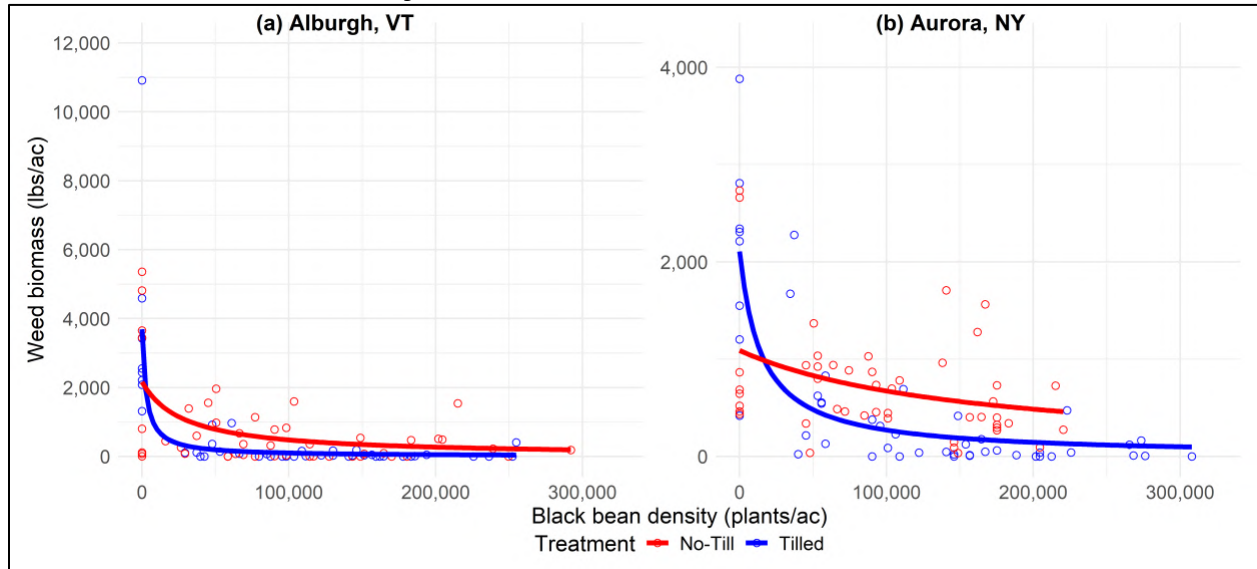


Figure 2. Effect of black bean density (plants/ac) on weed biomass (lbs/ac) in no-till and tilled system in (a) Alburgh, VT and (b) Aurora, NY pooled over 2022 and 2023. The red lines and data points represent the no-till trials and the tilled trials are denoted in blue as indicated by the legend.

As the density of black beans increased, weed biomass exhibited a non-linear decline (Figure 2). However, the impact of black bean density on weed suppression was stronger in tilled systems. In both Alburgh and Aurora, tilled trials showed a sharp initial decrease in weed biomass with increasing density while no-till treatments exhibited a more gradual decline. While a significant reduction in weed biomass was observed with increasing black bean density in the tilled trials across both sites ($P < 0.001$), only the Alburgh no-till trials showed a statistically significant decline ($P < 0.05$). The Aurora no-till trials displayed a marginally significant decrease ($P < 0.1$), as indicated by the smaller reduction in weed biomass. On average, across black bean densities, weed biomass in Alburgh's no-till system was 749 lbs/ac, compared to 697 lbs/ac in tilled plots. A similar trend was observed in Aurora, where weed biomass in no-till plots averaged 716 lbs/ac, while tilled plots had a lower average of 577 lbs/ac.

Effect of black bean density on black bean yield

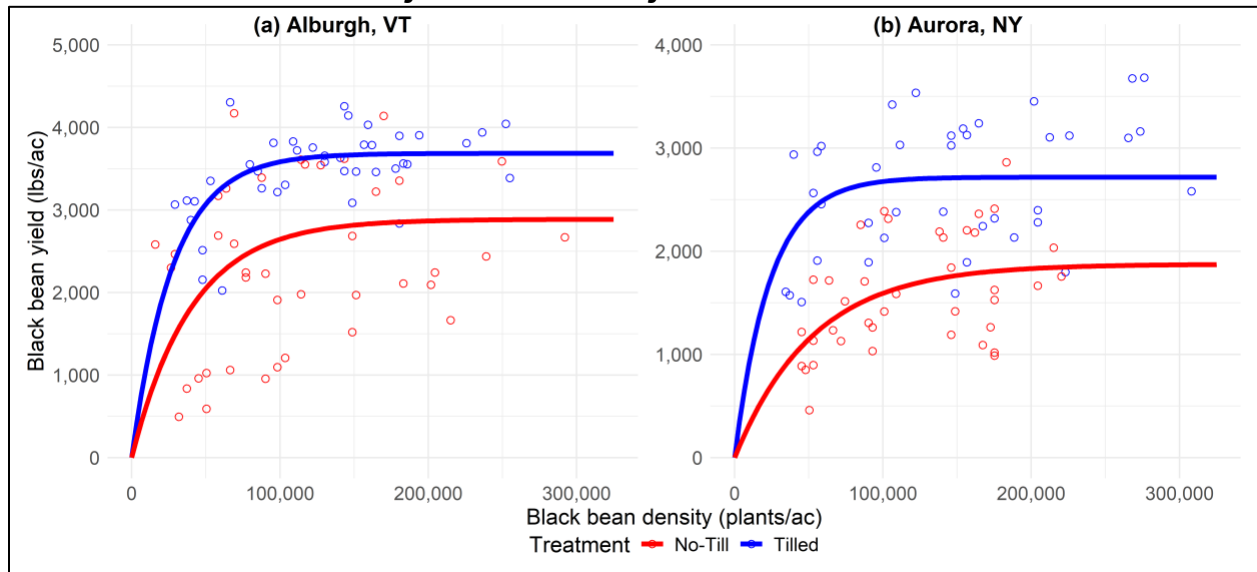


Figure 3. Effect of black bean density (plants/ac) on black bean yield (lbs/ac) in no-till and tilled system in (a) Alburgh, VT and (b) Aurora, NY pooled over 2022 and 2023. The red lines and data points represent the no-till trials and the tilled trials are denoted in blue as indicated by the legend. Black bean yield was adjusted to 14% moisture.

In Alburgh, black bean yield ranged from 2,025 lbs/ac to 4,306 lbs/ac in the tilled and 496 lbs/ac to 4,171 lbs/ac in the no-till. In Aurora, black bean yield ranged from 1,508 lbs/ac to 3,682 lbs/ac in the tilled and 461 lbs/ac to 2,862 lbs/ac in the no-till. As black bean density increased, black bean yield increased asymptotically in both sites and management systems. However, the maximum achievable yield was different in each site and management system. In Alburgh, the maximum yield was predicted to be 2,887 lbs/ac in the no-till trials ($P < 0.001$), while the tilled trials had a higher predicted maximum yield at 3,685 lbs/ac ($P < 0.001$). The average yield across black bean densities for Alburgh was 2,336 lbs/ac in the no-till trials and 3,481 lbs/ac for tilled trials. In Aurora, the maximum yield was predicted to be 1,874 lbs/ac in the no-till trials ($P < 0.001$), while the tilled trials had a higher predicted maximum yield at 2,717 lbs/ac ($P < 0.001$). The average yield across black bean densities for Aurora was 1,585 lbs/ac for the no-till trials and 2,632 lbs/ac for the tilled trials. Across both sites, yields from the tilled trials were consistently greater than yields from the no-till trials.

Effect of black bean seeding rate on partial returns

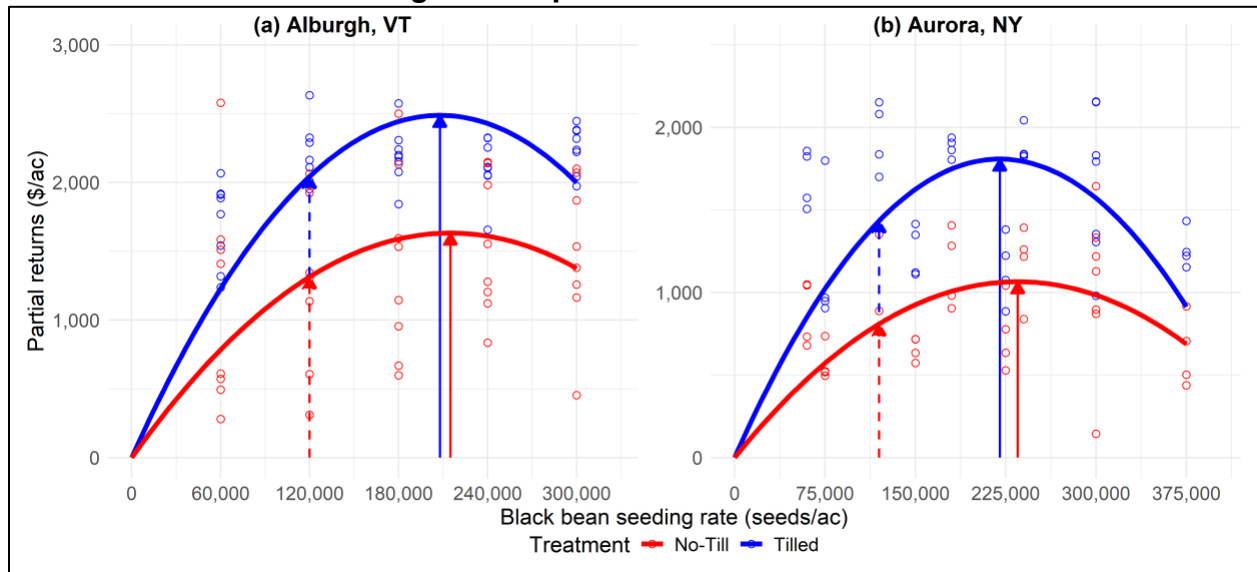


Figure 4. Effect of black bean seeding rate (seeds/ac) on partial profitability (\$/ac) in no-till and tilled system in (a) Alburgh, VT and (b) Aurora, NY pooled over 2022 and 2023. The red lines and data points represent the no-till trials and the tilled trials are denoted in blue as indicated by the legend. Vertical lines denote the recommended seeding rate for conventional black bean production at 30-inch-wide rows (120,000 seeds/ac, dashed line), and the predicted economically optimal seeding rate for each respective site and tillage system (solid line).

Table 4. Profitability characteristics for Alburgh, VT and Aurora, NY in 2022 and 2023 by site and tillage system.

| Site and tillage system | Optimal seeding rate for maximum partial return (seeds/ac) | Maximum partial return at optimal seeding rate (\$/ac) | Partial return at recommended conventional seeding rate* (\$/ac) | Gain in partial return at optimal vs. conventional seeding rate (\$/ac) |
|-------------------------|--|--|--|---|
| VT tilled | 207,877 | 2,488 | 2,043 | 445 |
| VT no-till | 214,937 | 1,632 | 1,314 | 318 |
| NY tilled | 220,144 | 1,809 | 1,434 | 374 |
| NY no-till | 235,036 | 1,066 | 810 | 255 |

*Conventional seeding rate was denoted at 120,000 seeds/ac

In conventional black bean production, growers typically plant at a seeding rate no greater than 120,000 seeds/ac. In organic tilled black bean systems, results from both Alburgh and Aurora indicate that maximum partial returns were achieved at seeding rates exceeding 200,000 seeds/ac with gains in partial returns up to \$445/ac relative to the conventional seeding rate (Table 4). In organic no-till black bean systems,

profitability was maximized at seeding rates greater than 210,000 seeds/ac across sites with corresponding gains in partial returns up to \$318/ac compared to the conventional seeding rate.

Discussion

Higher seeding rates in organic black bean production serve multiple functions, particularly in no-till systems with rolled-crimped cereal rye. While increasing seeding rates beyond 120,000 seeds/ac resulted in only modest yield gains, our profitability analysis suggests that the optimal seeding rate exceeds 200,000 seeds/ac. This recommendation is driven by two key factors: (1) stand establishment challenges, particularly in no-till systems, and (2) the price premium associated with organic black beans.

Black bean stand losses were observed in both the tilled and no-till trials, with no-till plots experiencing greater establishment challenges due to the thick cover crop mulch. This supports the use of higher seeding rates to compensate for stand losses and ensure adequate plant density for maximum yield potential. While improved planter technology and optimized planting conditions could enhance establishment in no-till systems, increasing seeding rates remains a practical strategy for mitigating these risks. Nitrogen availability likely played a role in yield differences between systems, as cereal rye can immobilize soil nitrogen, making it less accessible to black beans early in the season prior to the development of root nodules and nitrogen fixation from *Rhizobium* bacteria. Without sufficient nitrogen, plant vigor and yield potential can be compromised, reinforcing the need for optimized fertility management in no-till systems.

In addition to compensating for stand losses, higher seeding rates provided an effective weed management strategy. At sufficiently high black bean densities, weed suppression in no-till plots was comparable to that in tilled plots. This suggests that higher plant populations can reduce weed abundance even in the absence of mechanical cultivation. However, excessive populations can also lead to competition between black bean plants, emphasizing the need to balance seeding rate decisions with expected stand losses, nitrogen availability, and weed abundance. Although not observed in our research, lodging and increased risk of foliar diseases are additional concerns associated with high seeding rates that should be considered when making decisions.

The price premium for certified organic black bean significantly influences the economic viability of higher seeding rates. In 2023, organic food-grade black beans were priced at \$0.63/lb, approximately 1.5 times higher than conventional black beans (\$0.40/lb). As a result, very high seeding rates may not be justified in conventional black bean production, where increased seed costs may not be offset by higher returns.

Although partial return estimates from this analysis were higher in tilled systems, profitability comparisons between tillage systems should be interpreted with caution. This analysis did not account for several field management costs, including fuel and

labor associated with roller-crimping, seedbed preparation, or cultivation, nor did it include the cost of cereal rye seed in the no-till system. Potential long-term benefits of no-till management, such as improved soil health, soil structure, and erosion control, were also not captured in this partial budget analysis. While no-till systems may offer labor and time savings, this evaluation focused solely on black bean seed costs and seeding rates. No-till black bean production remains a viable option, particularly if challenges related to crop establishment and fertility management can be addressed. Future research should focus on strategies to reduce stand losses and optimize nitrogen management in organic no-till black bean systems.

Key Takeaways:

1. **Higher seeding rates (>200,000 seeds/ac) compensate for establishment challenges in no-till systems.**
2. **Increased plant densities improve weed suppression**, reducing reliance on tillage and cultivation.
3. **Profitability is strongly influenced by the organic price premium**, making higher seeding rates a viable strategy in organic systems.
4. **Organic no-till systems require further optimization** to match the productivity and profitability of tilled systems.

Acknowledgements

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Land Acknowledgement

Musgrave Research Farm in Aurora, NY is located on the traditional homelands of the Gayogohó:nq? (the Cayuga Nation). The Gayogohó:nq? are members of the Haudenosaunee Confederacy, an alliance of six sovereign nations with a historic and contemporary presence on this land. The confederacy precedes the establishment of Cornell University, New York state and the United States of America. We acknowledge the painful history of Gayogohó:nq? dispossession and honor the ongoing connection of Gayogohó:nq? people, past and present, to these lands and waters.

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